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N65-26081 (ACCESSION NUMBER) 1 (THRU)
15 (PAGES) 07 (CODE)
Cr 63383 (NASA CR OR TMX OR AD NUMBER) (CATEGORY)

FACILITY FORM 602

ANNUAL SUMMARY REPORT
1 September 1963 - 31 August 1964

Grant Number NsG-74-60

1093-22 1 September 1964

Department of ELECTRICAL ENGINEERING

THE OHIO STATE UNIVERSITY
RESEARCH FOUNDATION
Columbus, Ohio

REPORT
by
OHIO STATE UNIVERSITY RESEARCH FOUNDATION
COLUMBUS, OHIO 43212

Sponsor	National Aeronautics and Space Administration 1520 H. Street Northwest Washington 25, D. C.
Grant Number	NsG-74-60
Investigation of	Receiver Techniques and Detectors for Use at Millimeter and Submillimeter Wave Lengths
Subject of Report	Annual Summary Report 1 September 1963 - 31 August 1964
Submitted by	Antenna Laboratory Department of Electrical Engineering
Date	1 September 1964

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ANNUAL SUMMARY REPORT
1 September 1963 - 31 August 1964

I. INTRODUCTION

The purpose of this research program is to investigate various detection, generation, measurement, and receiver techinques, both conventional and non-conventional, in the millimeter and submillimeter wavelength regions. This report summarizes the results during the grant period Sept. 1, 1963, to Aug. 31, 1964, and outlines briefly the activities planned for the period Sept. 1, 1964, to Aug. 31, 1965.

II. RESEARCH RESULTS FROM SEPT. 1,1963, TO AUG. 31, 1964

The research results accomplished during the semi-annual period from Sept. 1, 1963, to Feb. 29, 1964, were discussed in report 1093-19.[1] In summary, during that period, we successfully tested the radiometer in its aperiodic mode with the Golay detector,* investigated the carbon bolometer as a detector, and successfully lowered the laser crystals to liquid helium temperatures for solid-spectroscopy studies. Since then progress has been made on the following:

A. The Submillimeter Radiometer

The arrival of the Germanium bolometer, purchased from the Texas Instruments Co., has made a great improvement in the characteristics of the radiometer. It has eliminated the channel spectra problem mentioned in the semi-annual report 1093-19.[1] It has a signal-to-noise ratio of approximately 20 times that of the Golay cell for frequencies lower than 100 cm^{-1}, despite the fact that its sensitivity was measured

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* A paper describing the experimental observations concerning the interferometric receiver will be published soon in the Proceedings of the Polytechnic Institute of Brooklyn Symposia, Series XIII, Quasi-Optics.

to be approximately 1.5×10^{-11} watts in comparison with the expected 5×10^{-12} watts. A number of measurements in the aperiodic mode were made of the water vapor absorption over the five-meter path length of the interferometer and very good spectra were obtained (see Fig. 1). An analogue-to-digital tape system has also been designed, built, and added to the radiometer so that the aperiodic mode data now can be fed directly to the computers for performing the Fourier Transforms to obtain the spectra.

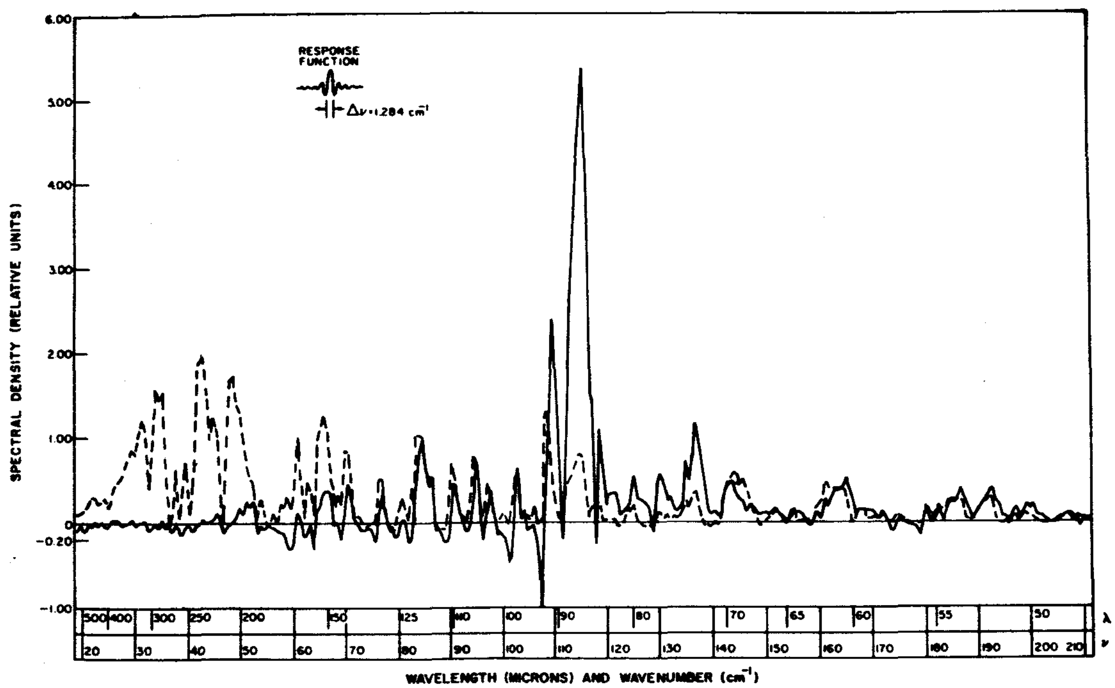

Fig. 1. Spectral density curve of short-path atmospheric absorption obtained by the aperiodic method using a 500 LPI mesh (solid line) and a 200 LPI mesh (dotted line). Both meshes were oriented at 45 degrees, γ_{max} was 7800 microns, source temperature was 230°C and a black polyethelene filter and the TI detector were used.

Initial periodic tests have been successfully made on the ratiometer. Results obtained are primarily due to the improvement of the time response of the Texas Instruments detector over the Golay cell and the use of a rotating drum to generate the reference signal. This permits elimination of the time-delay difference between the detector signal and the reference signal. Photographs of the radiometer with the new modifications are shown in Figs. 2 and 3.

As a result of the successful radiometer tests, we plan to (a) measure the water vapor absorption in a controlled atmosphere over a longer path length, and (b) measure the solar radiation. The purpose of the water vapor absorption measurement is to estimate the usefulness of the submillimeter region for communications in the presence of water vapor. The purposes of the solar measurement are to obtain information about solar radiation in the submillimeter wavelength region and to determine the depth of atmospheric window in that wavelength region.

In the water vapor study the following have been accomplished: The literature search on the water vapor absorption in this frequency region has been made. The vacuum covers for the radiometer are being constructed and will permit the instrument to be evacuated and the absolute water vapor absorption spectrum measured. This measurement may be made in conjunction with the 50-ft. long absorption cell at our laboratory. Water vapor absorption line positions have also been computed from the theoretical calculations of Randall, Dennison, Ginzberg, and Weber[2] up to 76 cm^{-1}, as shown in Fig. 4; absorption lines at frequencies above 75 cm^{-1} are already given by Bennedict in Ref. (3).

Regarding the solar measurements, further communications have been established with the High Altitude Observatory, Climax, Colorado; the Sacramento Peak Observatory; and the Kitt Peak National Observatory. The High Altitude Observatory reported a much greater water content than expected; and the ceolostat at the Sacramento Peak Observatory is heavily scheduled and is mechanically difficult to use with our radiometer. The Kitt Peak National Observatory has informed us that the McMath Solar Telescope is not heavily scheduled at the present time, and that some 24" auxiliary heliostats may be available. Thus our present plan is to correspond further with the Kitt Peak National Observatory and to use that facility if possible.

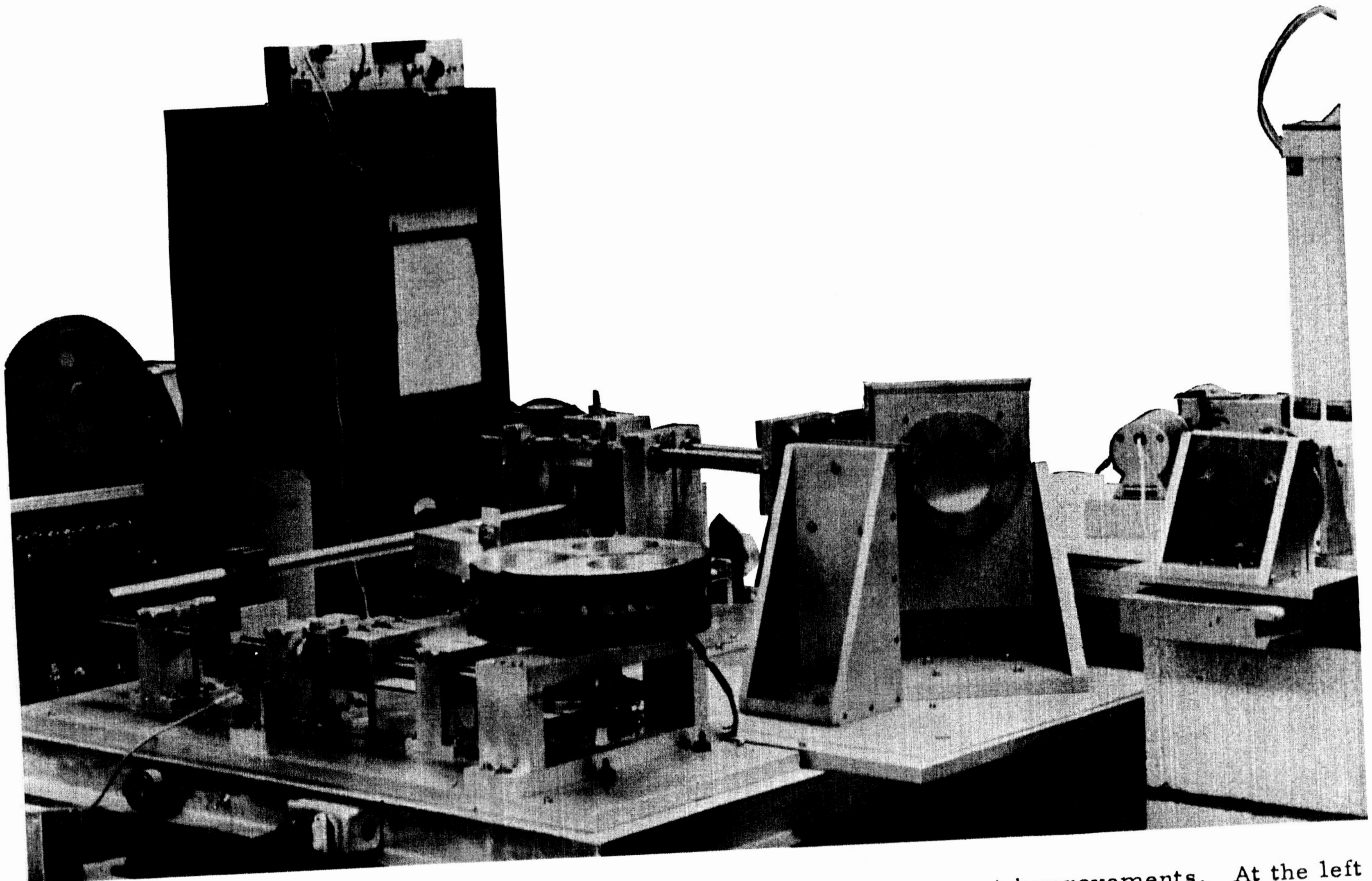

Fig. 2. A general view of the instrument showing some of the more recent improvements. At the left is the automatic data processing unit which automatically reads and records on perforated tape the data acquired during aperiodic mode operation. Mounted above the cam is the new periodic-mode reference signal generator which enables phasing adjustments to be made to compensate for detector time delay and mechnaical backlash. At the right is the new Texas Instrument low-temperature germanium bolometer which has greatly improved the instrument performance.

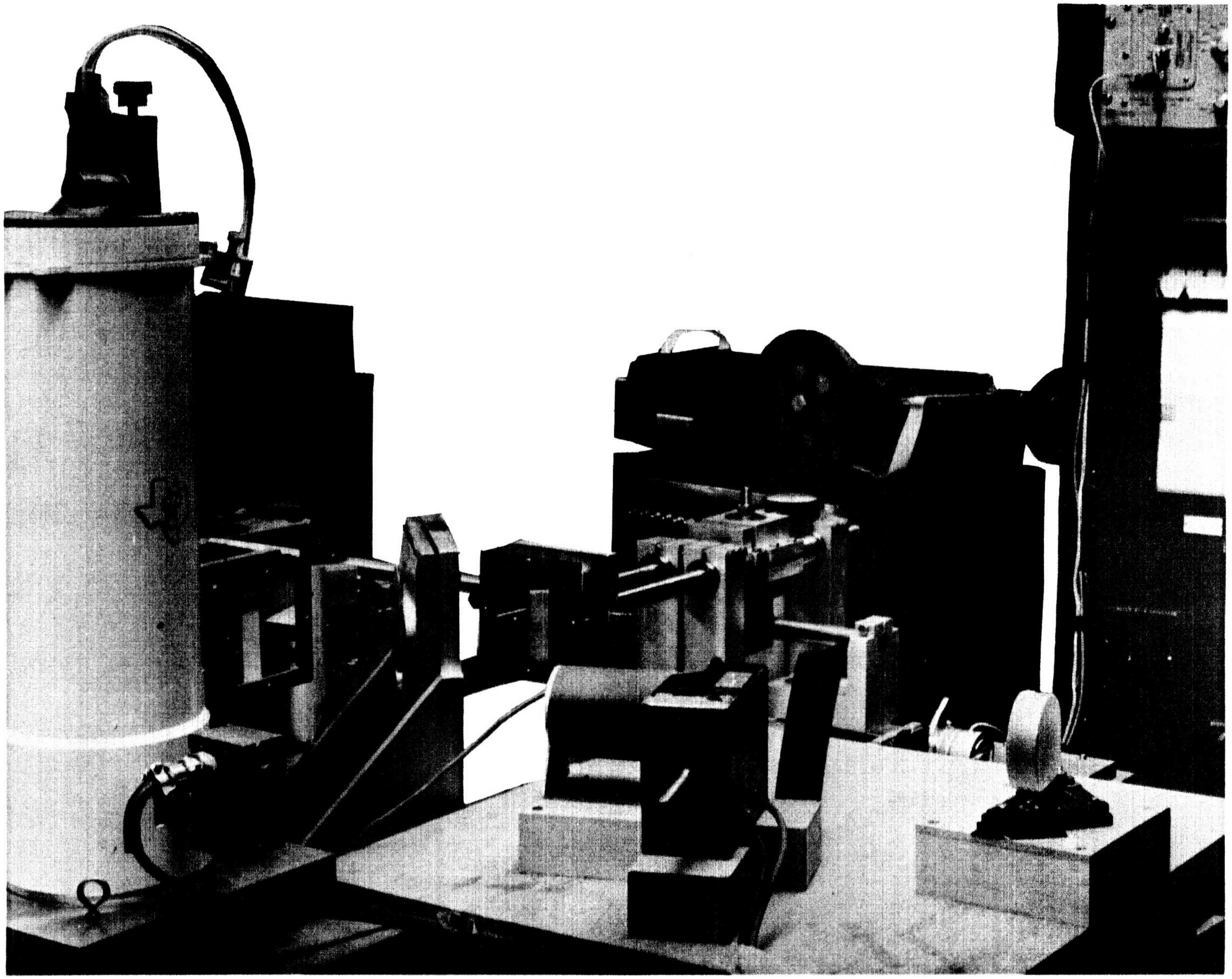

Fig. 3. A view of the new data processing unit and the new pivot point assembly. The latter has contributed to better mechanical stability of the instrument in periodic mode operation.

$\nu(cm^{-1})$	Transition($J_T - J'_{T'}$)	$\nu(cm^{-1})$	Transition($J_T - J'_{T'}$)
.68	$6_{-5} - 5_{-1}$	44.80	$7_0 - 8_{-6}$
6.07	$2_2 - 3_{-2}$	46.25	$1_{-1} - 2_{-2}$
10.78	$9_{-3} - 10_{-7}$	47.07	$5_{-1} - 5_{-3}$
12.67	$3_1 - 4_{-3}$	47.49	$9_{-2} - 10_{-8}$
13.00	$10_{-4} - 11_{-8}$	47.61	$6_0 - 7_{-4}$
14.54	$6_6 - 7_2$	50.64	$10_7 - 11_5$
14.60	$5_5 - 6_1$	50.64	$10_8 - 11_4$
14.73	$6_5 - 7_3$	50.64	$2_1 - 3_3$
14.88	$3_3 - 4_{-1}$	51.42	$6_0 - 5_2$
15.54	$5_4 - 6_2$	52.50	$6_1 - 7_{-5}$
15.70	$4_4 - 5_0$	53.17	$8_1 - 9_{-5}$
16.25	$6_{-2} - 7_{-6}$	53.31	$4_{-4} - 4_{-2}$
16.63	$7_6 - 8_4$	54.43	$2_{-1} - 2_1$
16.63	$7_7 - 8_3$	55.60	$1_{-1} - 2_{-1}$
18.52	$1_{-1} - 1_1$	56.52	$10_{-3} - 11_{-9}$
20.62	$4_3 - 5_1$	57.25	$5_0 - 6_{-6}$
20.62	$5_1 - 4_3$	57.36	$2_{-1} - 3_{-3}$
21.41	$8_7 - 9_5$	58.94	$6_2 - 7_{-2}$
21.41	$8_8 - 9_4$	58.95	$6_0 - 6_{-2}$
25.01	$2_{-2} - 2_0$	58.98	$6_{-2} - 6_{-4}$
27.80	$8_{-2} - 9_{-6}$	62.79	$6_{-1} - 7_{-7}$
28.62	$10_{-1} - 11_{-7}$	62.81	$8_{-4} - 9_{-8}$
29.67	$9_8 - 10_6$	63.04	$7_3 - 8_{-1}$
29.67	$10_5 - 9_9$	63.57	$8_4 - 9_0$
30.40	$3_2 - 4_0$	64.03	$4_1 - 5_{-1}$
32.21	$4_2 - 5_{-2}$	64.08	$3_{-1} - 3_0$
36.59	$3_{-3} - 3_{-1}$	64.36	$3_2 - 4_{-4}$
37.06	$0_0 - 1_0$	64.47	$10_1 - 11_{-5}$
37.16	$9_0 - 10_{-6}$	64.98	$9_5 - 10_1$
38.14	$10_{10} - 11_6$	64.98	$9_4 - 10_2$
38.14	$10_9 - 11_7$	65.89	$8_3 - 9_1$
38.23	$7_{-3} - 8_{-7}$	67.69	$10_6 - 11_2$
38.52	$2_1 - 3_{-1}$	67.76	$10_5 - 11_3$
38.69	$6_{-1} - 5_3$	68.06	$3_0 - 4_{-2}$
38.74	$3_{-1} - 3_1$	68.24	$4_0 - 4_2$
38.82	$7_5 - 8_1$	69.70	$8_{-2} - 8_{-4}$
39.61	$7_4 - 8_2$	71.41	$6_{-4} - 5_2$
40.45	$4_{-2} - 4_0$	72.12	$7_2 - 8_0$
40.48	$8_5 - 9_3$	72.14	$2_{-2} - 3_{-2}$
40.48	$8_6 - 9_2$	72.56	$7_{-2} - 8_{-8}$
41.06	$2_0 - 2_2$	73.38	$3_1 - 3_3$
42.65	$6_3 - 7_1$	74.22	$5_{-3} - 5_{-5}$
43.19	$7_{-1} - 8_{-5}$	74.88	$7_1 - 8_{-3}$
44.14	$6_{-3} - 5_1$	75.59	$4_{-3} - 4_{-1}$
44.37	$9_6 - 10_4$	76.66	$7_2 - 8_{-4}$
44.37	$9_7 - 10_3$		

Fig. 4. Submillimeter water vapor absorption lines.

B. The Carbon Bolometer Studies

Investigation on the carbon bolometer has continued. In particular, the resistivity of the carbon bolometer material has been determined experimentally as a function of temperature, and the static response for a carbon bolometer has been calculated from the heat equations. The entire investigation in the static behavior carbon bolometer has already been written as an M. Sc. thesis and is being published as a contractor report. A second report on the dynamic behavior (i.e., sensitivity) of the carbon bolometer is forthcoming. This investigation is significant in that it can be applied to other bolometric detectors as well as to the carbon bolometer. However, since we have found the Ge bolometer to be so much better in practice than the carbon bolometer, the study of the carbon bolometer will be terminated in September, 1964.

C. Submillimeter Laser Studies

In July we obtained the first successful measurement of the solid spectroscopy at submillimeter wavelength on the exchange-coupled levels of concentrated ruby at liquid helium temperature. Results are shown in Fig. 5. A comparative measurement of the spectrum ot the same ruby at visible light wavelengths and room temperature is given

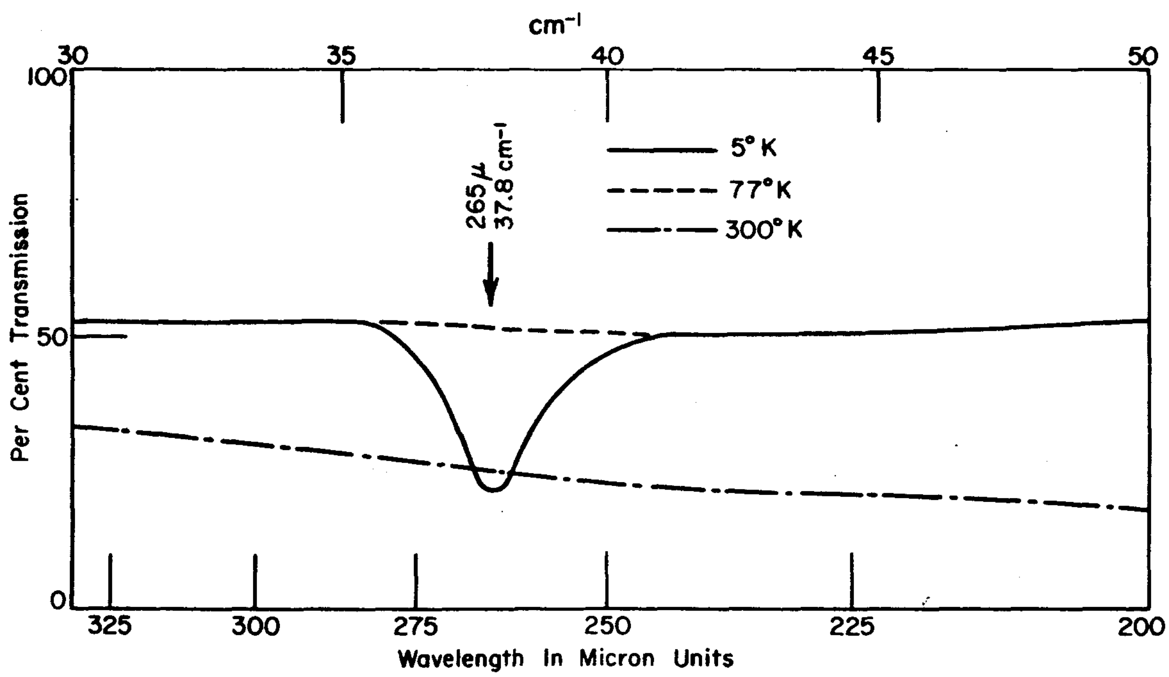

Fig. 5. Far infrared absorption spectrum of ruby containing 4% Cr^{3+}.

in Fig. 6. Comparing those with the studies of antiferromagnetic and ferromagnetic resonances by Kisliuk, Schawlow, and Sturge,[4] we see that the absoprtion is most likely due to the exchange-coupled levels in the ruby, but a precise identification of the transition is not possible with these preliminary data.

Recently, results have also been reported by Mathias, Gebbie, Kimmitt, Crocker, Findlay, Stone, Robb, Patel, McFarlane, Faust, and Garrett[5] on far infrared-submillimeter gas lasers operating at 50.70μ, 52.39μ, 54.7μ, 55.68μ, 68.33μ, 72.15μ, 72.7μ, 78.4μ, 85.05μ, 88.46μ, 89.73μ, 93μ, 106μ, 118.8μ, 124.4μ, 126.1μ, 132.8μ, and 340μ.

This gave added stimulation to our submillimeter laser studies. Consequently, we have begun a research program to construct a five-meter long cw and pulsed submillimeter laser complete with pumping and filling stations. The achievement of this laser oscillation will allow us to provide a stronger source for submillimeter water vapor absorption studies, to provide a monochromatic source for investigations of material properties such as the refractive index of materials, to provide a unique submillimeter amplifier, to provide a strong source for submillimeter instrumentation studies, and to provide an experimental set up to investigate new gas lasers or to study the mechanisms of laser radiation in existing gas lasers. Any one of these programs will lead to significant contributions to the submillimeter techniques.

D. Miscellaneous Programs and Publication Plans

1. The report on correlation radiometer by K. Fujimoto has been published in I. E. E. E. Trans., PGMTT Vol. 12, p. 203, March, 1964.

2. The experimental work on submillimeter radiometer has been reported in the B. P. I. Symposium on Quasi-Opitcs in June, 1964, and will be published in its proceedings in November, 1964.

3. The work on cross-relaxation effects in millimeter masers has been completed as an M. Sc. thesis and is published as a contractor report.

4. The studies on the carbon bolometer have been submitted as an M. Sc. thesis and will be published as a contractor report. The analysis of the sensitivity of the carbon bolometer will be written

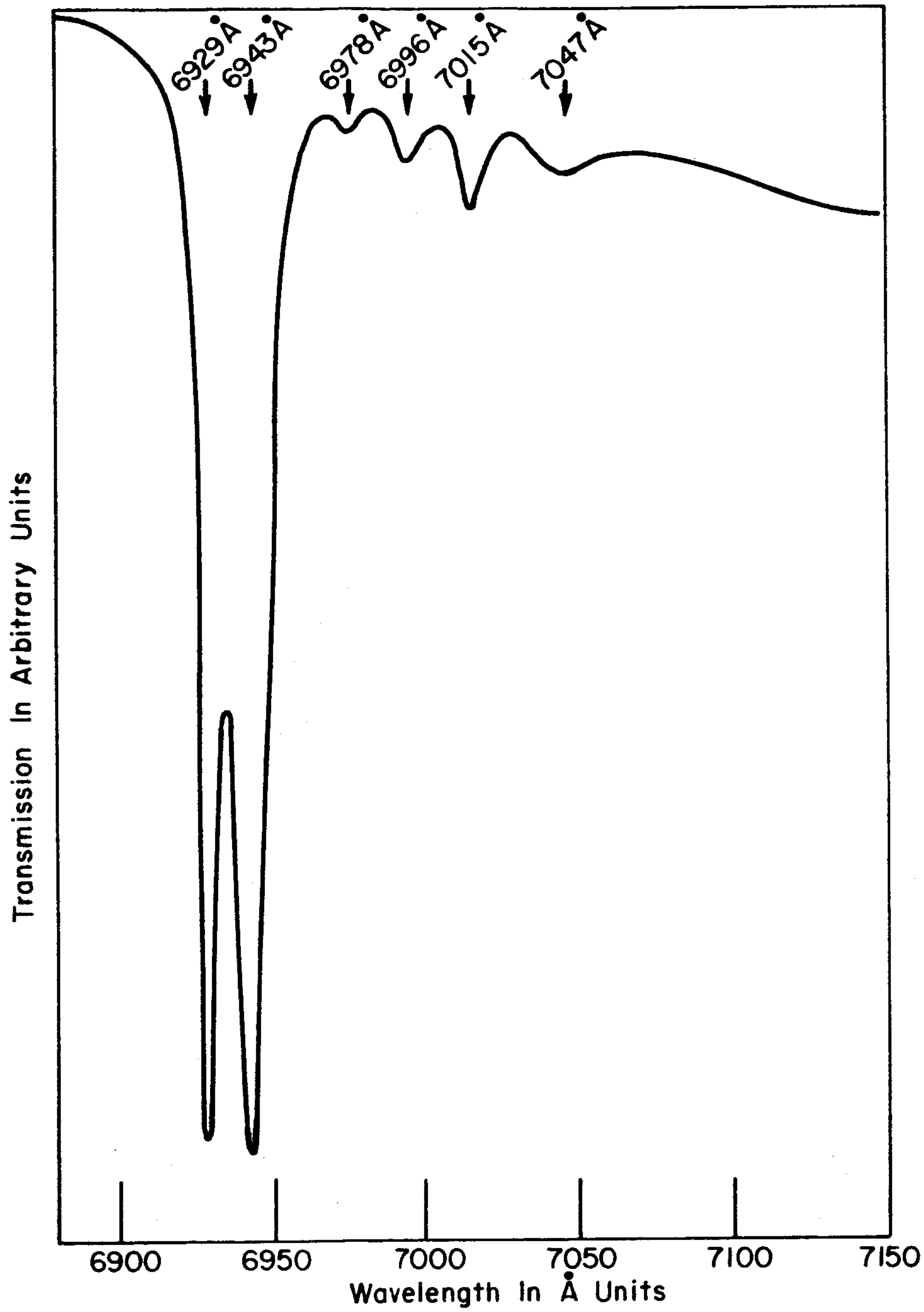

Fig. 6. Visible absorption spectrum of ruby containing 4% Cr^{3+}.

as a second report in the near future. Plans are being considered to publish this work in some scientific journals.

5. Preliminary studies of the effect of partial coherence on mixing of pulsed laser radiations, which is particularly important in submillimeter applications, have been made theoretically. This is an M. Sc. thesis and will be completed soon.

6. Some experimental studies of the tapered light pipe as a submillimeter transmission line were presented in Report 1093-20.

III. FUTURE RESEARCH PLANS

Basically, we propose to continue our dual program of research on submillimeter radiometers and submillimeter lasers, with some change in emphasis.

In the submillimeter radiometer program, we expect that the study of the radiometer characteristics will be completed in the Fall of 1964. Thus the major research in this area will be the use of the radiometer for solar measurements and for water vapor absorption measurements. These two programs will be persued alternatively (i. e., one at a time) depending upon the exact arrangement that can be made with Kitt Peak National Observatory.

In the submillimeter laser program, a shift in emphasis will be made to gas lasers. The usefulness of the gas lasers in the 50μ to 400μ range was discussed in Section II. We feel this should take priority with respect to the solid spectroscopy studies because of the obvious usefulness of the gas lasers.

In addition, the solid spectroscopy of laser materials and the eventual development of the solid-state submillimeter laser, as well as a preliminary investigation on the generation of submillimeter waves via optical mixing will be carried out as time permits.

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